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ANATOMY, HISTOLOGY OF ORIBATID GUT AND THEIR DIGESTION

KAZIMIR TARMAN

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INTRODUCTION

In the field of the study of feeding habits of oribatids important progress has been made during the last twenty years through investigations by P. W. Murphy (1950, 1953 and 1956), G. Riha (1951), R. Schuster (1956), J. A. Wallwork (1958), R. Hartenstein (1962 a, b, c) and J. P. Woodring (1963). We are now informed of their type of food, their feeding preferences, and their role in decomposition processes (M. S. Ghiljarov, 1949, 1965; W. Kühnelt, 1950; J. van der Drift, 1951; J. Nosek, 1954, 1957; J. Nef, 1957; C. A. Edwards and G. W. Heath, 1963), but we know very little still about the digestion of oribatid mites.

Befor we can answer this last question we must know much more about the anatomy and histology of the digestive tract in oribatids. We are still using the old data supplied by the study by A. D. Michael, Observations on the Anatomy of Oribatidae, which was published 85 years ago. During the last twenty years a paper was published on the anatomy and histology of related Acaridiae mites by T. E. Hughes (1950). The very recent and informative paper by N. Tarras-Wahlberg (1960) has given us only few remarks on the alimentary canal of the oribatid *Diapterobates humeralis*.

During our investigations we have made histological preparates of 17 species of oribatids, namely adults, nimphs, and larvae. Parafin sections were stained by Mallory method. The thickness of sections is from 7 to 10 microns.

Observations of the feeding behavior and food passage were made for *Steganacarus magnus* C. L. Koch 1855 (typical macrophytophagous species), *Hypochthonius rufulus* C. L. Koch 1863, *Euzetes globosus* Nic. 1855 (non-specialists), *Oppia* sp. and *Metabelba gracilipes* Kulcz. 1902 (typical microphytophagous species). The animals were cultured in petri dishes with bottom of moist plaster of Paris, under room temperature ranging from 16^0 to 18^0 C.

Anatomy and Histology of Digestive Tract

At the very beginning of the digestive tube there is mouth cavity with mouth opening. The bottom of this cavity is formed of by the hypostome, and the upper wall by the labrum. Left and right of the mouth cavity we find four large salivary glands whose excreta are emptied into the cavity. The next

part is a muscular pharynx, which is followed by a very long oesophagus. In no one of 17 species we could find the crop or ingluviens which was mentioned by M i c h a e l. From pharynx to ventriculus the oesophagus is a very narrow canal which "perforates" the brain or cerebral ganglium. The stomach or ventriculus is very big and of sphaerical or pear-like shape (fig. 1). Into this ventriculus flow excreta of two proventricular glands, which are situated left and right of the oesophagus. In species with transparent skin we could see these two glands also in living animals (*Hypochthonius rufulus*, nymphs of *Camisia* and *Hermannia*). The last third of the stomach is connected by two small openings with two big and blind coeca (figs. 2 and 6). One of them is on the right and one on the left side of the ventriculus. In species. *Hypochthonius rufulus, Nothrus silvestris* N i c. 1855; *N. biciliatus* C. L. K o c h,

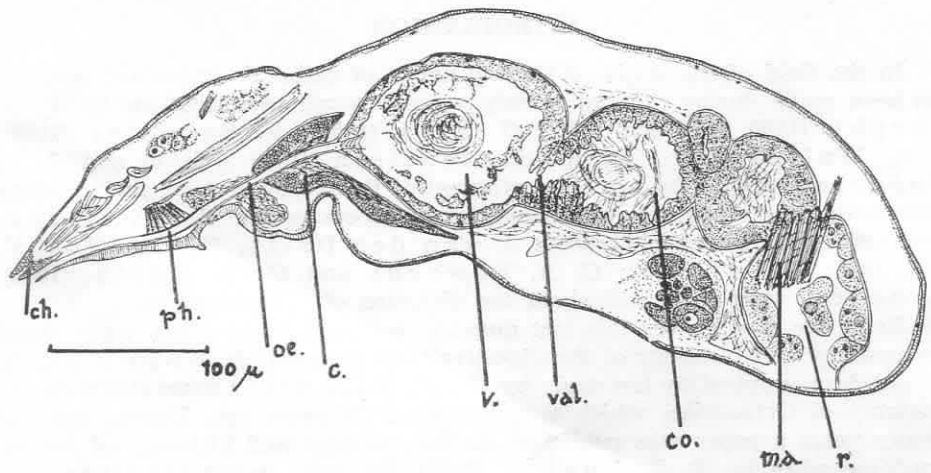

Fig. 1. *Hypochthonius ruflus*, longitudinal sectin through sagital line. Ch. = chelicera, ph. = pharynx, oe. = oesophagus, c. = cerebellum, v. = ventriculus, val. = valvula, co. = colon, r. = rectum, m. a. = muscles of anal plate

1844; *Platynothrus peltifer* (C. L. K o c h) 1840; *Hermannia convexa* (C. L. K o c h) 1840; *Camisia segnis* (H e r m a n n) 1804; the coeca are very big and bag-like formations. Their cavities are much bigger than is the cavity of the stomach. They fill considerable part of body cavity among the axial parts of digestive tract and lateral body walls (figs. 2, 6, 7 and 8). The coeca in the species, *Metabelba gracilipes, Hydrozetes lacustris* (M i c h.) 1882; *Ceratozetes gracilis* (M i c h.) 1884; *Euzetes globosus, Parachipteria punctata* (N i c.) 1855 and *Galumna lanceatus* O u d m s. 1900 are in comparison with the stomach not so big and are tube-like. Very small coeca are in the species, *Ceratoppia bipilis* (H e r m.) 1804; *Amerus troisii* (B e r l.) 1883; *Liacarus xylariae* (S c h r a n k) 1803; *Steganacarus magnus* and *Oribotritia* sp., but they all have a big stomach resembling a bladder.

The colon which succeeds the stomach is smaller and of sphaerical shape (figs. 1 and 2). A valvula exists between the stomach and colon (fig. 1). In contracted position the valvula has a triangular opening.

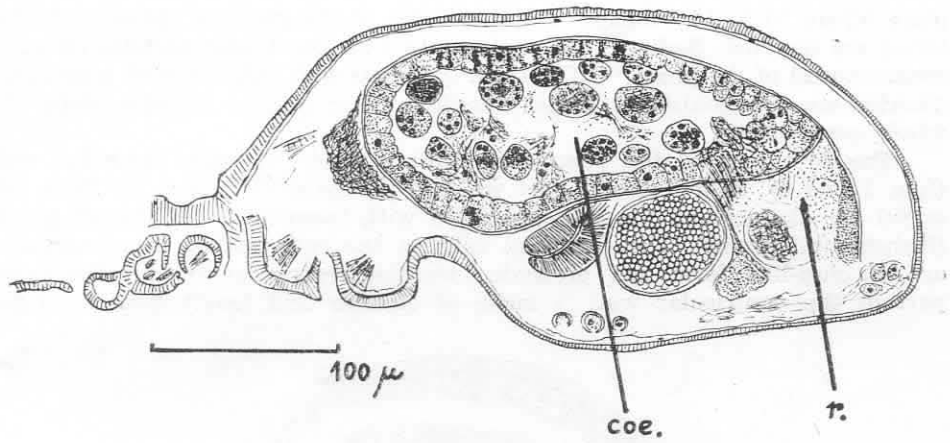

Fig. 2. *Hypochthonius rufulus*, longitudinal section made leteral of sagital line. Coe. = coecum, r. = rectum

The bag-like rectum (fig. 8) is the next part of the digestive tract. It ends in the anal opening which is long and narrow and surrounded by anal plates. Special muscles attached to chitinous levers move the anal plates asunder. When anus is open the contractions of the muscles in the rectal wall push out the fecal pellet.

The epithelium of the mouth cavity, pharynx, and oesophagus consists of flat cells with the chitinous intima at the distal end. The chitinous intima (fig. 3) has its greatest thickness in the dorsal wall of the pharynx, at the

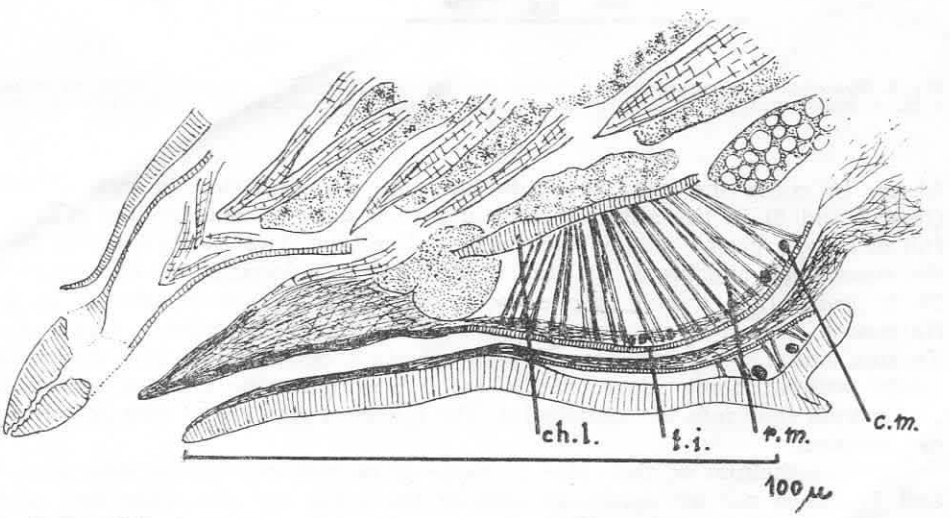

Fig. 3. *Hypochthonius rufulus*, longitudinal section through the pharynx region. T. i. = tunica intima, r. m. = radial muscles, c. m. = constrictor muscles, ch. l. = chitinous lamella for muscles insertion

place where 10 to 15 bands of radial muscles of the pharynx (Musculi dilatatores) are inserted. Radial muscles alternate with constrictor muscles (Musculi constrictores) of the pharynx. The thick chitinous wall together with constrictor muscles are antagonists of radial muscles. There are no muscles along the whole oesophagus.

The first part of the ventricular wall is made of cubic epithelial cells (figs. 1 and 6). In the second part we find prismatic cells (fig. 1). Their cell nuclei are distinct and the cells are filled with intensively red stained grains (fuchsinophil grains). The epithelial cells in the end part of the ventriculus are of club-like form and protrude into the ventricular cavity. The outer part of the ventricular wall is made of circular and longitudinal muscular

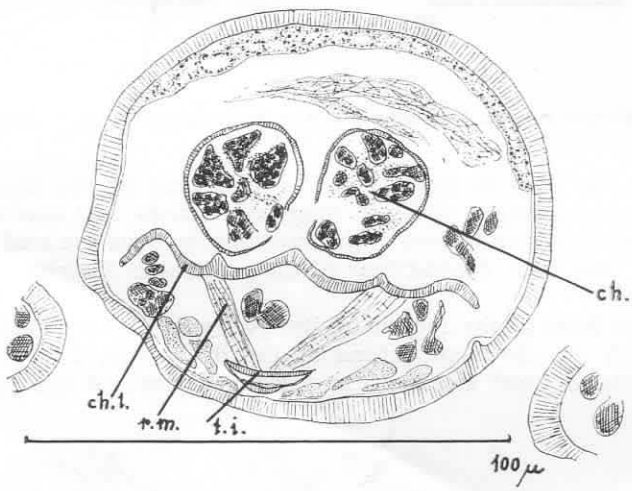

Fig. 4. *Hypochthonius rufulus*, cross section through the pharynx region. T. i. = tunica intima, r. m. = radial muscles, ch. l. = chitinous lamella for muscles insertion, ch. = chelicerae with their muscles

fibres. In coeca the cells of epithelium, are differentiated in cubical cells (figs. 2 and 6) in the anterior part, and very tall and bladder-like cells are full of secreta grains, stained blue with aniline blue. These cells separate from the coecal wall and break out (figs. 2, 6, 7 and 8; holocrine type of secretion). Their grains flow then in the coecal cavity. Such a type is common in the *Hermannia* and *Hypochthonius* species. In *Galumna*, *Ceratozetes*, *Hydrozetes*, *Euzetes*, and *Liacarus* the coecal cells secrete their products into the coecal cavity without being separated from the wall (apocrine type of secretion). The secreta flow into the ventriculus. The nuclei of ripe coecal cells are always degenerated.

The epithelium of the colon is made of narrow prismatical cells (figs. 1 and 7). Since not all epithelial cells in the colon are the same size, cross section make impression as if the inner surface of colon were folded (figs. 1 and 7). The cells have distinct nuclei and intensively stained cell bodies.

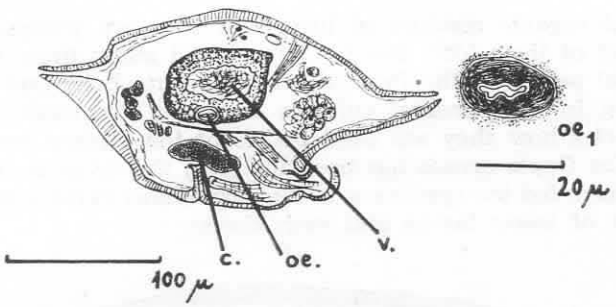

Fig. 5. *Hypochthonius rufulus*, cross section through the anterior part of the ventriculus. V. = ventriculus, oe. = posterior part of oesophagus, oe$_1$. = oesophagus in bigger magnification, c. = cerebellum

Prismatical cells in the anterior part of the rectum have a fringed border (fig. 8). In the border blue stained (with aniline blue) mucose secreta are collected. The cell bodies however are stained with acid red stain (with fuchsin red). In the posterior part of the rectum, where it passes into the anal opening, epithelial cells are more flat; in the last fifth the epithelium is extremely thin and covered by solid chitinous intima (proctodeum).

Under the basal membrane of the ventriculus, coeca, colon and rectum are firm circular and longitudinal muscles, the latter arranged in ribbons.

Feeding Habits and Digestion in Oribatid Mites

Many authors have already written on the role of oribatids in the decomposition of dead plant residues and soil fungi. Especially good and well gathered information on the behaviour of oribatids has been given in the recent book "Soil Biology", by A. B u r g e s and F. R a w (1967). On the basis of investigations made by various authors oribatids are classified in the macrophytophagous type (S c h u s t e r) or the macrohumiphagous type (D u n g e r) microphytophagous or microhumiphagous type and nonspecialists. Fungi and bacteries

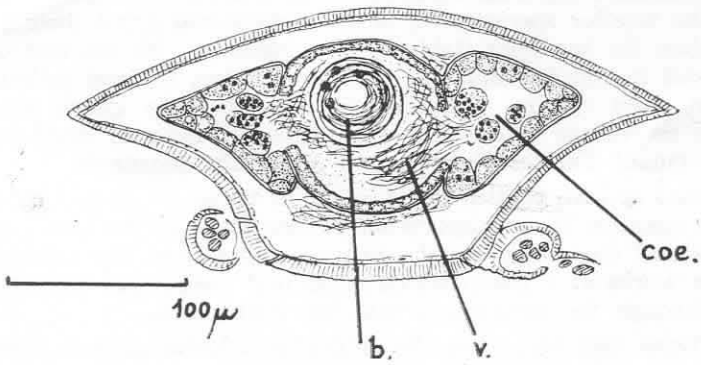

Fig. 6. *Hypochthonius rufulus*, cross section through the ventriculus (v.) and anterior part of coeca (coe.) with their opening into the ventriculus. B. = ball of food particles

grow on dead organic residues of litter and they are without doubt a very important part of their food. But we have found many times in the digestive tract and fecal pellets of the *Parachipteria punctata* hairs and chitinous parts of *Collembols*. In experimental cultures we have also made observations of the same species how they ate dead bodies of the diptera larvae and of the nematodes. The *Oppia ornata* has been found in the caves in the human feces also and we have fed the specimens of *Hypochthonius rufulus* with dead bodies of nematodes, of insect larvae and with cheese.

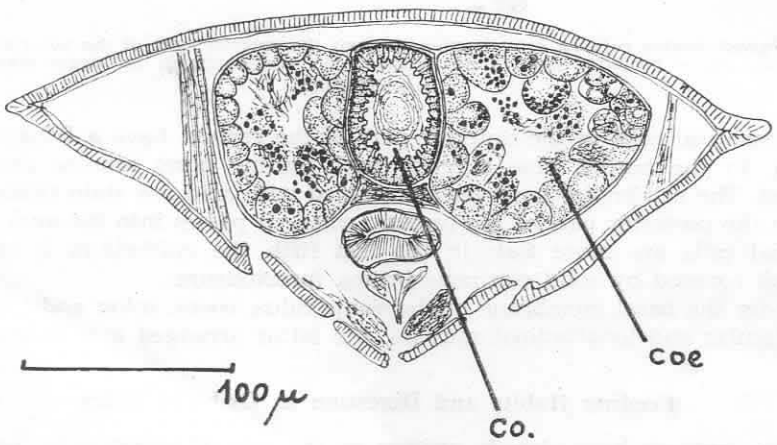

Fig. 7. *Hypochthonius rufulus*, cross section through the colon (co.) and middle part of coeca (coe.)

The shape, structure, and the role of chelicera in the first step of ingestion were discussed by Schuster (1956) and Wallwork (1958). Wallwork informs us that, "These organs may chew, grind, or tear, food material prior to its ingestion". We have made the same observation to learn about mechanical role of the oribatid chelicerae. Measures of particles in fecal pellets of animals show that the smaller species with smaller chelicerae grind their food more effectively than the big ones (table 1). Experiments with the diet of various oribatid species in starch grains has been illustrative. In fecal pellets of small and medium sized species *(Hypochthonius rufulus)* no starch grains were intact, while the grains whose size was bellow 12 microns could pass intact through the gut of *Euzetes globosus* and *Metabelba gracilipes*.

Fragmented or torn particles of dead plant tissue are passed by chelicerae to the mouth opening. The transportation is then made by the action of pharyngeal muscles and moderated by the saliva coming from the salivary glands. The pharynx works as a pump which sucks and pushes the bit of food from the mouth through the oesophagus into the ventriculus.

The particles that come into the empty ventriculus at first float in it in a confused way. After some time they gather. In this way it forms with special movements of ventricular walls a small ball of food particles in the

centre of the ventriculus. The gland cells of ventriculus and proventricular glands secrete digestive secreta that could be seen in cross sections as fuchsinophil grains around the ball. The whole ball is afterwards enveloped with a blue layer of coecal secreta (stained with aniline blue). This outher layer is coagulated and compact and looks in cross sections as if it were a shell around a ball. To this small ball stick new food particles that enter the ventriculus.

Among them occur secreta of ventricular and proventricular glands. The next layer of coecal secreta forms then around them. In this way the ball of food grows bigger and it shows in cross section a great number of circular layers (figs. 1 and 6). This formation of the ball is attended by active movements of the ventriculus and coeca. At the same time the ball "oscillates" in the ventricular cavity. The direction of coecal waves is from the posterior to the anterior part, each of the wave lasting from 10 to 15 seconds. Coecal movements push coecal secreta into the ventriculus.

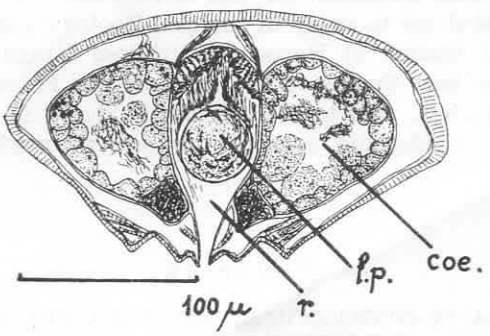

Fig. 8. *Hypochthonius rufulus*, cross section through the rectum (r.) with fecal pellet (f. p.) and posterior part of coeca (coe.)

The time of digestion in the ventriculus is evident from table 2. We have seen that the passage of food through the ventriculus is very quick; during this time it is impossible that much of the ingested food could be used.

Ventriculus pushes the food through the widely opened ventricular valvula into the colon. Here the ball lies quiet and its size grows smaller and smaller and its contents more compact (figs. 1 and 7). The time of the passage of food through the colon is longer (see the table 2). Here resorption processess of fermented substances and of water are taking place. The resorption of water is completed in the rectum. The time of food retained in the rectum is also evident in table 2.

Defecation is affected by strong constriction of valvular muscles and of muscles in the rectal walls.

The form and colour of fecal pellets vary; they depend on the type of food and species of animal. The surface of fresh fecal pellets of *Hypochthonius rufulus, Metabelba gracilipes, Oppia* sp., that eat plant remains or microphyts, is glittering due to their water content. Fecal pellets of *Steganacarus magnus*

fed with wood tissue are more dry, with short points of ingested particles projecting from their surfaces. But the same species when cultured on the diet of algae *Pleuroccocus* fecal pellets like those of *Hypochthonius rufulus* or *Metabelba gracilipes*. The colour of fecal pellets is frequently dark grey or black. The colour of fresh fecal pellets of *Steganacarus magnus*, fed with the wood of newly fallen branches of the limetree, is yellow and after some time it becomes dark grey or black, because of the action of microorganisms.

The useful effect of digestion remains unknown. In our experiments the animals were able to use only the coagulated contents of dead *Pleurococcus* cells, chewed and opened by chelicerae. Cells that were not broken passed through the gut with coagulated but whole content.

ACKNOWLEDGEMENTS

Above all I thank UNESCO for the scholarship which was awarded to me and which enabled me to study in the Soil Zoology Laboratory at Rothamstead Experimental Station at Harpenden (United Kingdom). Furthermore I wish to express my best thanks to the head of the Entomology Department, Mr. Dr. K. Mellanby, and to the late Dr. F. Raw in whose laboratorium of soil zoology a considerable part of the present work was done during winter 1959/60.

Povzetek

ANATOMIJA IN HISTOLOGIJA PREBAVILA PRI ORIBATIDAH IN NJIHOVO PREBAVLJANJE

Glavni vir podatkov o anatomiji oribatidnega prebavila je še vedno 85 let stara razprava Michaela (1883). V novejšem času je le Hughes (1950) obdelal prebavilo pri oribatidam sorodnem podredu akaridij (Acaridia). Raziskovalec Tarras-Wahlberg pa se je v svoji razpravi zelo skopo dotaknil anatomije prebavnega trakta.

Pri novejših raziskovanjih smo anatomsko in histološko obdelali 17 vrst oribatid. Hkrati smo opazovali tudi način prehranjevanja in prebavljanja pri štirih vrstah. Izsledki so prikazani v tekstu in priloženih histoloških risbah. Prebavno cev oribatid sestavljajo: ustna votlina, farinks, dolg in ozek ezofagus, ventrikel, kolon in rektum. Na ventrikel se priključujeta z izvodili še levi in desni, slepi vrečasto ali cevasto oblikovani divertikel. Žlezne celice so v sluznicah ventrikla in divertiklov (cekov). V ventriklu nastane večslojna kroglica, ki po eni uri in pol do dveh urah zapusti ventrikel. V kolonu ostane ta kroglica okoli dve uri. Tu se resorbirajo hranilne snovi in voda. Še daljši čas ostane kroglica v rektumu, kjer se voda nadalje resorbira. Barva in oblika svežih iztrebkov je odvisna od vrste hrane in od vrste živali. Na površini in v notranjosti iztrebkov se razmnožijo potem glive in bakterije, zaradi katerih iztrebki počrnijo.

Table 1. The size of particles in fecal pellets of various oribatids

Species	Size of animal in microns	Type of ingested food (all sizes in microns) microphyts, spores, algae, hyphae	macrophyts, wood and bark	Filter paper
Hypochthonius rufulus	630—680	3—10	2—19	—
Euzetes globosus	1070—1150	3—40	20—40	—
Metabelba gracilipes	950—1050	3—20	10—50	—
Steganacarus magnus	1100—1200	3—25	8—50	40—120

Table 2. The times for the passage of food through various parts of oribatid gut (in hours, temp. range from 15° to 17° C and r. h. 90 %).

Species	Ventriculus	Colon	Rectum
Hypochthonius rufulus . . . . . (51 specimens)	1 1/2—2	2	2 1/2—3 1/2
Nanhermannia nana . . . . . (nimphs, 10 specimens)	1 1/2—2	3	2 1/2—3 1/2
Oppia sp. . . . . (10 specimens)	1 1/2—2	2	2 1/2—3 1/2
Phthiracarus pavidus . . . . . (15 specimens)	1	5—6	2 1/2—3 1/2

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